Discussion.

Mr. ALFRED GILES, President, said that if there were any truth in the old adage that in the multitude of counsellors there was wisdom, the Papers before the meeting should prove it. He was sure, in considering the advantages offered by the Overhead Railway at Liverpool as compared with the pattern which it followed, the Elevated Railway in New York, the Institution was very much indebted to the Authors for the investigations they had made, and he called upon the members to accord to those gentlemen their most cordial thanks. Mr. Giles.

Mr. J. H. GREATHEAD wished to emphasize one or two points in regard to the two Tables given in the first Paper. The first had reference to the weight of electric motors compared with steam-locomotives. On the Liverpool Overhead Railway the electric motors weighed 20 per cent. of the total weight of the train exclusive of the motors, whereas on the Metropolitan Railway in London the locomotive weighed just double, say 40 per cent. of the weight of the train. On the other hand, the tractive effort of which the electric motors were capable was, in the case of the Liverpool Overhead Railway, 120 lbs. per ton of train, compared with 71 lbs. per ton of train of which the steam-locomotives were capable. That seemed to be a very important point. There was also another feature, that not only could a much greater tractive effort be obtained by electricity, but by adopting motor-carriages, a correspondingly greater adhesion was secured. Table B illustrated that point, because on the Liverpool railway the adhesion was 115 lbs. per ton of train, whereas on the District Railway, calculated in the same way, it was only 61 lbs. per ton of train. And, finally, the maximum tractive force per ton of motor or locomotive was very striking. On the Liverpool railway electricity gave 730 lbs. tractive effort per ton of motor as a maximum at starting, while on the District Railway the tractive force was only 234 lbs. per ton of locomotive, or less than one-third of that obtained at Liverpool in starting the train. Mr. Greathead

Sir WILLIAM FORWOOD said that during the past four or five years he had been pretty well saturated with all that apper- Sir William Forwood.

Sir William
Forwood.

tained to overhead railways, but he had still learned a great deal that was new and interesting from the Papers. He was the chairman who had survived the construction of the Overhead Railway, and as such was entitled to some congratulation; for though it had bristled with a great many problems which had been a source of vast interest to the engineers of the line, it had also been full of difficulties which had caused the chairman and directors of the undertaking many headaches. They had published a prospectus undertaking to construct the line at a certain cost, and naturally they had been asked to live up to that prospectus; and when they were faced day by day with new developments, with drains underneath the surface of the ground of which they had never heard, and with all sorts of difficulties which meant a considerable extra cost to the shareholders, it naturally was a matter of some anxiety to the directors. He was glad to be able to say that after ten months' working, the shareholders had been paid not only a preference dividend, but also 1 per cent. upon ordinary capital. This was entirely due to the employment of electric traction for the railway. Naturally, as a layman, he could not pretend to enter into many of the scientific problems which had been treated in the Papers, but perhaps some of those present might say, "This is a very interesting railway, but what practical use is it going to be? is it an experiment, or is it going to be the forerunner of the application of electrical traction elsewhere?" That was a point on which he could speak. He believed, from all he could see, that it was going to be the forerunner of the application of electrical traction on a very considerable scale; for when the construction of the line had been nearly completed, which was a great improvement upon any elevated railway in America, the means to be adopted for traction had to be considered. The line was commenced with the idea of using steam, which was used upon the overhead railway in America; but after visiting America, and seeing what had been done in electrical traction, he felt that in England, if possible, something better than had been done in America should be attempted, and he was proud to say it had succeeded. There was nothing in America comparable with the electric railway in Liverpool. Naturally the directors were face to face with two problems. In the first place, they wanted to be quite sure that the railway would be economical if worked by electricity, otherwise they would soon have found themselves in the bankruptcy court; in the second place, they wanted to be quite sure that it would be a reliable railway, otherwise it would be utterly useless to adopt electricity as the motive power to convey

men of business hurrying to and fro in their daily vocation. It was only after very deliberate consideration that they were able to decide upon the adoption of electricity. They had the advantage of the experience gained on the City and South London Railway, and also of what had been done in America, and they had made up their minds—not without considerable misgivings—to go in for electricity. The cost of steam-plant would have been £37,000; the cost of electrical equipment was £67,000 to £70,000; therefore the first outlay was very considerable: but, having made up their minds to employ electricity, they were determined—acting under the advice of their engineers—to have the very best electrical equipment that could be obtained, and their success was due largely to the accomplishment of that resolve. It was agreed that the manufacturers who supplied the electrical plant should be compelled by contract to run the line for the first two years at a given price per train-mile. He did not know that it had had a great effect upon the contractors, because he believed that they would have done their work thoroughly well in any case; but, at the same time, it was a prudent course for the directors to adopt. He was glad to say that the result had been very highly satisfactory. In the first place, with regard to cost, the Electrical Construction Corporation had been paid 4*d.* per mile for traction during the first ten months of working. Their outlay was carefully watched, and finding that the trains were running with perfect regularity and without break-downs, and finding also that the contractors were making money out of the contract, at the end of that period, though the contract ran for two years, the Company stepped in and said—“Gentlemen, we put an end to your contract.” And since the first of January last the Company had been running the railway on its own account. He was glad to be able to state that this had resulted in a saving in January of £150; in other words, 5½ miles of railway were run at a cost of 3½*d.* for locomotive expenses. He thought that was very satisfactory. The engineers had stated—and he fully agreed with them—that when the line was opened to the length of 7 miles, a further reduction would be made on the 3½*d.* Then came the question as to reliability, because if the railway was subject to break-downs, it would soon lose the passenger traffic. He might state that there was an enterprising line of penny omnibuses running the whole length of the railway, and had there been many break-downs on the line, the traffic would soon have been transferred to the omnibuses below. But since the opening of the railway ten months ago, although a five minutes’ service of trains had, with the exception of the first two months, been

Sir William
Forwood.

Sir William Forwood. maintained, nearly 96 per cent. of the trains had been punctual, and during the last week but one, 99 per cent. of the trains were punctual. That was a record which he did not think was equalled in the railway world, but the experience of those present was no doubt much greater than his own on that point. The railway had given much satisfaction to the commercial community of Liverpool; not only was it regular, but there was an absence of noise and dirt, and it was a perfect treat to ride upon the Overhead Railway. There were ladies who made frequent journeys in the day for pleasure. That statement might provoke a laugh, but he could assure the members present that, on visiting Liverpool, they would not be satisfied with one journey upon the Overhead Railway. It disclosed one of the finest prospects in the country. It passed along the whole line of the docks, and afforded passengers a view of some of the most magnificent ships in the world. Beyond the docks was the estuary of the Mersey, which of itself was a sight which had few equals in England. He would say to all the members and associates of the Institution, that the directors would be delighted whenever they came to Liverpool if they would call at the office, and ask for an order to see the railway and the generating-station. He gave that invitation in the sincere hope that it might be availed of. He wished to acknowledge the sense of the great services that the directors had received from their engineers, Sir Douglas Fox and Mr. Greathead, and also from Mr. Parker, who had been in charge of the electrical equipment of the line. Of course it was a novel thing. He knew that the directors had felt timid on many points; they were thankful for the courage their engineers had given them on those points, and he hoped within the next few years the railway would be completed for the whole distance originally contemplated; he also believed, before any great length of time elapsed, the Company would be able to pay a 5 per cent. dividend to the shareholders. That was a point to which he attached great importance, for although engineers might think only of constructive success, the question was, after all, one of dividends; and he was sure that all would be pleased that this, the first real electrical railway in England, had not only given satisfaction to the travelling public, but was also earning substantial dividends for the shareholders.

Sir Douglas Fox.

Sir DOUGLAS FOX would say, as Sir William Forwood had so very well put it, that the problem, which had been to some extent solved at Liverpool, was one that had caused a great deal of anxious thought to all connected with it. The engineers owed a

great deal of their success to the fact that they had practical men at the head of affairs in connection with the Company. The directors were, without exception, Liverpool men; they knew what was required to accommodate the traffic, and, with the plain common sense which was found in that city, they told their engineers exactly what they wanted, and so made the duty of providing it much simpler. Not only so, but he wished to say, that his colleague Mr. Greathead and he, had felt that they were exceptionally fortunate in several circumstances surrounding the arrangements in connection with this work. Not only had they had a board of directors who showed full confidence in them from beginning to end, and such excellent representatives in Liverpool as Mr. Francis Fox and Mr. Cottrell, but they had in their contractor, Mr. Willans, a mechanical engineer of considerable talent, who, with his able assistant, Mr. Hudleston, had done everything in his power to assist in the work. Mr. Hudleston's assistance had been especially valuable. The railway as shown on the plan might look very simple, but he could assure the members that, in his experience, he had never known a case in which there was so much intricate adjustment necessary, before it was possible to lay out the line in its present perfect state. It had to be literally threaded through the midst of a very complicated system of cross-over roads, dock-lines, warehouses and existing railways, and the engineers were tied on every side by the authorities, headed by their kind friends (for they had shown every desire to assist the Company) Mr. Lyster, the Dock Engineer, on the one side, and Mr. Boulnois, the City Engineer of Liverpool, on the other. The fact that Mr. Hudleston had been formerly an officer of the Dock Board, and, therefore, thoroughly understood their requirements, had enabled him to give great assistance to the engineers in carrying out their arrangements. Not only was that so, but a great deal of ingenuity was exercised in connection with this work by those holding somewhat subordinate positions. The clever and novel way in which the erection of the structure was carried out had been described. It was found desirable, for economical reasons, to deliver all the ironwork at the north end. There was a convenient yard connected with an existing goods-station, and the whole of the material was there delivered. It was decided by the contractor to commence at one end and work over-hand, and that had been done for nearly six miles. Although at first sight that might seem to be a slow process, it worked out exceedingly well, and a good deal of the detail was well executed by the sub-contractors. There was also considerable difficulty at first in

Sir Douglas
Fox.

Sir Douglas
Fox.

connection with the manufacture of the steel-plates for the platform of the viaduct; and here again, in connection with the Phœnix Foundry Company, a Member of the Institution, Mr. Goodwin, had rendered valuable assistance. What was desired with reference to this railway was, first of all (and there came in the influence of the directors), to have an economical and at the same time a thoroughly durable structure, which could be cheaply maintained, and which would be, as far as possible, fire-proof, because the line ran through a very inflammable neighbourhood. Even since the opening of the railway, it had been proved how important that was, and how utterly fatal it would have been to have adopted a timber structure. A large timber-yard had been on fire, the flames passing right across the railway, but doing it little or no damage. Of course they were tied, as engineers unfortunately almost always were, for headway, and, consequently, were obliged to introduce the bracing necessary to resist wind-pressure in a very cautious manner, and just get it in where it was possible. One of the important things necessary was to decide upon the most economical span for the normal structure. That was a matter which his colleague and he had discussed very fully; and, rightly or wrongly, they had come to the conclusion, that, with piers of that height, the most economical span was 50 feet. They called it the normal structure; but it was rather a case where the exception proved the rule, for only one-third of the length was normal, and two-thirds of it were composed of abnormal spans. That was, of course, due to the inter-threading that he had spoken of. They commenced with the idea that for a considerable length they would be able to escape this inconvenience by deviating the lines underneath; but, in spite of a large expenditure upon such works, they had been obliged to introduce abnormal spans to the extent above mentioned. In connection with that he wished to mention that over £80,000 out of the total cost was represented by the slewing and re-paving of the dock lines underneath the structure, and the accommodation works. When they had resolved upon the 50-foot span, the next most important point was, what sort of floor were they to have? They wanted as noiseless a floor as possible, which would be easily accessible for painting, which would be very stiff vertically, which would tend to help them in the cross-bracing of the structure, which could be cheaply and rapidly manufactured and be easily made water-tight. After a good many designs were considered, they at last fixed upon the "Hobson" system, it being the first time, he believed, that it had been used, and that certainly

had given great satisfaction. He would not weary the members with lists of figures, but he should like to direct attention to the results of the testing of the flooring as given in the Paper. A very important point was, as usual in the case of passing through towns, to make the structure drop-dry. Those who had any experience of that requirement would appreciate the sorrows of engineers; but they had done their best in that direction, and, he thought, had been fairly successful, thanks to that particular flooring. They had found from experience—learning always more by mistakes than by successes—that, among small matters of detail, it was important, where that or any similar flooring was used, not to attempt to mix sand with the asphalt, but to put in pure asphalt in spite of the additional cost, for that saved trouble afterwards. The platform had given wonderful stiffness to the structure, and it had proved even quieter than had been anticipated. He had been rather afraid there might have been a severe drumming noise, but there was not. It was less noisy than most platforms which trains ran over, and that, combined with its strength, was a great advantage. It allowed perfect ventilation of the permanent-way timbers, the attachment of the rails by means of fangbolts without impairing the insulation of the electric conductor and a proper system of drainage. The question of foundations was a matter requiring some consideration, when it was remembered that there were at least 1,200 separate piers; and, if anything in the way of a luxurious foundation had been attempted, it would very soon have been heard of in the cost. As a matter of fact, nothing could be simpler than the system adopted—a block of concrete, bolts built into it, and a wrought-iron column fixed by those bolts direct on to it, and then the column protected by a very effective cast-iron boss, which entirely prevented any wagon or other passing load from striking against the column. The traffic had been running for nearly a year, and Mr. Cottrell, the Company's Engineer and Manager, had told him only yesterday that there had not been any sign of settlement, as far as he was aware, throughout the whole length. The great point was in such a case to permit of only very moderate pressure upon the foundations. He wished to say a word about the parapet. He did not know that it was very beautiful, but it had proved efficient. It was necessary that the parapet should be so arranged as to enable people to get out and walk to a station without danger if the train should stop outside; for otherwise the Board of Trade would probably have required special provisions. There was a parapet which practically gave a station-platform along the whole length

Sir Douglas
Fox.

Sir Douglas
Fox.

of the line, and at each span there was an ample refuge for the plate-layers. The parapet was very cheap and free from rattle. It fulfilled an unexpected use, as had been mentioned, namely, that for a considerable length it had been used for the purposes of carrying compressed air. Another very important point in all railways of that kind was to have sufficient stations; in fact, the perfect ideal would be to have a station of the whole length of the line. That could not be quite accomplished. The complaint the people made in Liverpool—he did not know whether they were any worse than the people in London—was, that they did not like to go by the railway, because when they alighted they had to walk 100 yards to their destinations, and that was their reason for travelling by omnibuses! To minimise that objection as far as possible, thirteen stations had been already constructed, and it was intended, in the 6 miles, to have no less than seventeen stations. He would like to say one other thing; it was not necessary, because there were a number of stations, to spend a great deal of money upon them. He thought that some success had been obtained in giving a fairly æsthetic appearance to the stations, and that at a very moderate cost. The outlay per station, including staircases, roofing, two platforms, turnstiles and everything complete, had averaged about £2,000, which could not be called excessive. There were no complicated or difficult engineering works on the line; it was more a matter of great detail, involving, he might mention, over 1,000 detail drawings, apart from the working-plans. There were two or three matters in which he must specially admit the indebtedness of the engineers to Mr. Hudleston. One was the Stanley swing-bridge, which was really a clever design for that particular position. It was not a large swing-bridge, but it was a peculiar one. It had two levels, and had to be arranged in a very restricted space, so that it could be fixed with a minimum interference with the existing traffic. The bridge was so arranged that it not only could swing as a whole, but was also a bascule bridge so far as the lower or dock lines portion is concerned. The lower half could be raised to allow barges with masts to pass underneath without interfering with the traffic on the overhead railway.

Mr. Giles. Mr. ALFRED GILES, President, asked if any way-leave was paid for the line.

Sir Douglas
Fox.

Sir DOUGLAS FOX replied that there was a rental paid to the Dock Board under agreement. He wished to point out that the superstructure of the railway was strongly braced longitudinally by the introduction of cluster piers at intervals, and that the

curvature of the line was overcome by the introduction of Sir Douglas triangular piers, so that all the spans, even on the curves, were ^{Fox.} rectangular. One point with reference to the tilting-bridges, of which there were two or three, was that they were so designed as to have all the appearance of ordinary spans; and, being in connection with the hydraulic-power available on the dock estate, they were moved in the simplest possible way. The permanent-way had proved highly efficient, although it was light and economical. One great advantage was its being kept strictly to gauge without difficulty by means of chubs which were solidly riveted on the platform. The Timmis automatic electrical signals were working satisfactorily, after certain improvements in detail had been introduced to prevent residual magnetism, short circuiting, and certain mechanical defects. The principal magnets, which worked the signals, give a pull of 34 lbs. at a distance of $1\frac{3}{4}$ inch, with 10 amperes. The Board of Trade inspection of the railway occupied four days, there being over 500 spans on the open portion, each of which, of course, had to receive careful examination. Those four days of testing gave a very interesting result incidentally, in reference to the handiness of electricity for the quick stopping and starting of trains. It had been found that the trains were thoroughly under control, and the work of testing could be carried on far more rapidly than he had ever known with ordinary locomotives. The test-load for the ordinary structure was four loaded trains, each weighted so as to be equal to a train with a full complement of passengers, and with the motor-bogies placed together in each train, instead of at the ends as in ordinary working. With this load, which amounted to about 13 cwt. per foot of each line of way on a 50-foot span, the deflections were very small. On a 40-foot span they were $\frac{1}{8}$ inch, and on a 75-foot span they were $\frac{1}{2}$ inch. On the Stanley Bridge, which from its depth would be expected to be very stiff, the load was far more severe. There, four of the heaviest Lancashire and Yorkshire tank-engines, weighing about 30 cwt. per lineal foot, were placed on each low-level line of way, in addition to the loading of the overhead line with 13 cwt. per lineal foot, making altogether about 4 tons per lineal foot of bridge, and the deflection was about $\frac{3}{8}$ inch at the nose of the bridge. It might be interesting to state what considerations had chiefly guided the engineers in deciding the question of motive-power for the railway. If locomotives were to be used, certainly the cost of the superstructure must have been increased. They could not have had anything like the same moderate rolling-load or such efficient starting and stopping as with the electrical

Sir Douglas Fox. arrangement. Locomotives would also have required much more expensive coal, which, with the water, would have greatly added to the weight of the trains. A more fatal objection however was this—that the Dock Board would not even allow smoking on its estate, and they were not likely to tolerate locomotive engines emitting sparks, which were much more dangerous to adjoining property than those connected with the electrical motors. For that reason alone it was decided that locomotives could not be used. They had carefully considered the question of the introduction of the cable system; but, of course, this was not a case in which that motive power would work out with any great advantage, because there were no steep gradients, except one little dip of 1 in 40 down and up again. With that exception, the line was practically level. When it was considered that the cable must be kept constantly running, involving a much greater loss of power than arose from the leakage of electric current, and that, in addition, they could not get anything like the speed between the stations that was obtained by means of electricity, they arrived rapidly at a decision to give the preference to the latter medium. He had found from recent careful investigations in the United States, that it did not prove economical to run a cable at a higher speed than 12 miles per hour, which would not give an average, including stoppages at stations, of more than 6 miles per hour, or about one-half the speed attained on this railway. The incessant noise caused by the cable was also a serious objection. He wished to confirm distinctly what had been said by Sir W. Forwood, the Chairman of the Company, that they were more than satisfied with the result. There was great punctuality of the train service, and he was glad to know that Mr. Cottrell was present, and no doubt would give the latest figures with regard to the cost of haulage on the line. One thing was certain—that it had been possible, by the introduction of electricity and of short trains, to give a most efficient local service. One great point in a line of that kind was to be able to run trains of a moderate length at very short intervals, rather than heavy and long trains at much longer intervals; and he could not help thinking that some of the metropolitan railways would obtain greater success if they were to adopt that plan. Even waiting three or four minutes at a station seemed a long time; whereas if very short trains were run that interval might be considerably shortened. He agreed with Mr. Greathead as to the advantage in this case of adopting motor cars, although under other circumstances, and especially where long and heavy main-line trains had to be dealt with, separate motors might be neces-

sary. An advantage of having two motor-cars, each having one motor, in the train, was that, like twin-screws in a steamer, in case of injury to one the other is available to drive the train, although of course at reduced speed. The total cost of the works, stations, and equipment was £90,100 per mile. The general works, comprising the whole of the foundations, superstructure and permanent-way cost £59,000 per mile. The stations had cost £4,600 per mile. The electric plant, including the conductor and the generating-station, cost about £7,700 per mile. The rolling-stock, including carriages and motors, cost £5,000 per mile. The accommodation-works, which were quite outside the general question of a railway of that kind, and represented chiefly the cost of altering the dock-lines and roads underneath, cost £13,800 per mile. In addition to these costs, there was the outlay of £4,400 per mile for the Act of Parliament, administration and other matters, making a total expenditure of £94,500 per mile. He thought that the Liverpool Overhead Railway was a successful solution of the problem Mr. Greathead and he had been asked to solve—viz., to provide for running short trains at rapid intervals, and at a low rate of cost. He hoped that this railway, which he thought bid fair to prove not only a mechanical and electrical, but also a financial success, might be the forerunner of greater things; and that the time might shortly come when not only trains of 40 tons weight would be dealt with, but also on main lines—especially tunnel lines—trains weighing 200 tons would be worked by electricity. He had no doubt that this, to secure which active effort was now being made, would come to pass in the near future; and that the considerable step in advance which had been secured at Liverpool would tend at any rate towards that important result.

Mr. KILLINGWORTH HEDGES considered the assertion that electrical railways were suitable for level ground, or districts with comparatively low gradients, and were not suitable for steep gradients, was not altogether correct. He might refer to Canadian practice, where there were already nearly 300 miles of electrical railway. The Niagara Falls Electrical Railway, a line about 11½ miles in length, from Chippewa, above the Falls, to Queenstown on the Niagara River, afforded an illustration of his statement—and many of those who had heard Professor G. Forbes' Paper on the scheme for utilizing the Niagara Falls on the American side, would be pleased to know, that, whilst the Americans had been talking about what they were going to do with that immense power, the Canadians had on a very small scale actually handled the

Sir Douglas
Fox.

Mr. Hedges. power, and since July, 1893, had utilized it for this railway. It ran along the road for part of the distance and was carried on an embankment like an ordinary railway until it reached a steep descent to the Niagara River, where the gradient was 1 in 21, and in some places, he had been informed, 1 in 19. Having had facilities to inspect the line, he had found there was not the slightest difficulty in working this electric railway up those gradients. The ordinary 30-foot American cars were used, with two motors, and as very often there was great stress of traffic, because the Niagara Falls and the surrounding country was essentially a holiday place, a trailing car was put on. One interesting point about the railway was that the whole of it was Canadian, even the rails having been rolled in Canada. The power was taken from the rapids above the Falls, a flume ran for a short distance into the power-house, where two turbines were fixed 60 feet down in the solid rock. From the outlet, water was taken by a tunnel which opened under the Falls, so that the water mingled with that of the Falls, and was no detriment to the beauty of the scenery. With regard to cost, having travelled through the United States, and having seen a great many figures with regard to different electric railways and tramways, he must say, in compliment to the Authors, that he could not find any case where the working expenses were as low as those given in the Paper. He had received a communication from Mr. Robert Gillham—a well-known American expert in cable-tramways—giving the working expenses of an elevated electrical road in Kansas City. It much resembled the Liverpool Overhead Railway, except that it was rather longer—20 miles, including the surface lines. The cost per train-mile for ten months ending January, 1894, came out, according to Mr. Gillham, at 12·9 cents, say, 6½*d.* per train-mile. Coal cost 1 dollar 75 cents per ton of 2,000 lbs., or 7*s.* The working cost of the Denver City cable-line for the last quarter was 14 cents, or 7*d.* per train-mile, the mileage being about the same. The train on the cable-line consisted of a dummy car with a gripper, and a trailing car; in the other case it was only one car. The number of passengers carried was approximately the same. He would ask the Authors if they could give any comparative cost of installation of cable-lines and electric-railways. There appeared to be a great desire to employ cable-lines throughout England, arising partly, he believed, through want of confidence in electric railways, and partly because of the overhead system. If gentlemen who had to do with municipal affairs would take a trip to America, they would

see the latter railways working well under every condition; and Mr. Hedges. with regard to unsightliness, he thought the superior advantages of electricity would be found to amply compensate for any drawback of that nature.

Mr. A. P. TROTTER said that it had been observed that in the Mr. Trotter. Liverpool line the head-room was restricted; but the electric features were not so restricted, and it was on account of the head-room that the engineers had been enabled to put the conductors above the level of the rails, instead of being obliged to place them below that level, as in the City and South London line, where their arrangement had led to great complication in the crossings. Three-quarters of an inch only, he understood, was sufficient to clear the conductor above the level of the rails. A feature of the Liverpool line, which surely would be of very great importance when electric traction became more common, particularly in light railways, was placing the motors upon the carriages and doing away with the locomotive. Head-room, again, was, he understood, the reason why locomotives were used on the City and South London, and why motors on the carriages were considered to be impracticable. A still more important reason for having motors on the carriages was that a number of motors could be used. In this case there were only two carriages, but with a greater number the multiplication of motors was easy, and brought with it very great economy. It was not generally known that Dr. John Hopkinson had a patent for the combination of electric motors in series or parallel. That patent had not been maintained, but it was interesting to know that the period would expire in July, 1895. It was strange that on the City and South London Railway that system had not been adopted, but it was employed on the Liverpool railway. The placing of motors in series and in parallel was a very great improvement in the economy of current in starting. The starting of a motor might be compared very accurately with the starting of an inward-flow turbine. When an inward-flow turbine was started, the whole head was unnecessary for the work of starting the turbine. The requisite momentum of the water could be obtained by much less head; but when the turbine got up speed, the centrifugal force checked the water, and finally the turbine worked at full load. Similarly with the electric motor, when the speed was low the current simply ran away to waste, and at last was checked when the motor got up speed by the back-pressure generated in the motor, not unlike the centrifugal force in the turbine. He directed attention to some diagrams, *Figs. 1 and 2*,

[THE INST. C.E. VOL. CXVII.]

H

Mr. Trotter.

Fig. 1.

ANALYSIS OF PART OF Fig. 3, MINUTES OF PROCEEDINGS INST. C.E.,
VOL. CXII, P. 246.

The full lines, marked Electrical Horse-power and Speed, are reproductions of curves in Fig. 3, Minutes of Proceedings Inst. C.E., vol. cxii. p. 246.

The chain-dotted line marked $\frac{dV}{dt}$ is the slope or differential coefficient of the speed curve, and gives the positive or negative acceleration.

The strong dotted line is the continued product of the acceleration of the speed at any instant, and of the mass (35 tons); and gives the acceleration horse-power, i.e., the horse-power required to set in motion at the given speed, on a level line, a frictionless train of 35 tons.

The fine dotted line gives the gravity horse-power, that is, the power expended in lifting, without friction, a mass of 35 tons, or the power developed by the falling of this mass, and is the product of the weight into the speed into the sine of the gradient. The transition from one gradient to the next being unknown, and the length of the train being neglected; the corners have been so rounded as to give a smooth resultant in the line of total calculated horse-power.

The full line marked Acceleration H.P. $\pm$ Gravity H.P. is the resultant total calculated mechanical horse-power, exclusive of friction. It is not carried to the end of the run as the instant at which the brake was put on is not known.

The gradients are shown on a time-scale, corresponding with the scale at the foot of the diagram.

in which he had analysed carefully the theoretical power required Mr. Trotter. for a specimen case on the City and South London line, the diagram of which had been furnished by Mr. Greathead, with a view of discovering the portion of power expended in starting, in climbing gradients, in pure traction and in friction. Before the train had attained a speed of 10 miles an hour, a very serious

Fig. 2.

DIFFERENCE BETWEEN OBSERVED ELECTRICAL HORSE-POWER AND CALCULATED MECHANICAL HORSE-POWER, WHICH EQUALS THE POWER EXPENDED IN TRACTION AND IN GENERAL FRICTION.

The dotted line shows assumed power, proportional to speed, and therefore in excess of actual power.
The shaded area represents the energy wasted in starting the train, which is to a large extent avoidable.

amount of energy, amounting to about 18 per cent., had been lost by current running to waste through the motors.

Mr. W. H. PREECE had, like many other members of the Institution, spent his holidays last year in the United States during the months of August and September, devoting special

Mr. Preece. attention to the working of the telegraphs and telephones of America, and also looking carefully into the questions of electric lighting, transmission of power, and other practical applications of electricity. Nine years had elapsed between his two visits to the States. In the year 1884 there was only one electrical railway there, and that in its experimental stage, viz., in the city of Cleveland. Last year he had found in the city of Cleveland a greater mileage of electric railway than there was in the whole of the United Kingdom. Throughout the States there were no less than 6,000 miles of railway worked by electricity. There were 6,900 motor-cars, and 4,000 trolley-cars working in conjunction with the motor-cars. At the Chicago Exhibition there was a track laid down for the special purpose of testing and examining all the exhibits which were shown, and he had had the pleasure of spending some hours with the electrical jury testing and examining a locomotive that weighed 30 tons. This locomotive was said to exert a pull of 6,000 lbs. on the draw-bar, not a very marked result, but still sufficient to draw a train of 500 tons weight along a level English railway. More than that, in the City of Baltimore there was an electric locomotive weighing no less than 80 tons, intended to draw trains weighing 1,200 tons through that city. The peculiar feature of the electric railways of the States was that up to the present time they had rather replaced horse-tramways than really introduced what were known as railways in this country; and, owing to the difficulty of climate, the cost of horse-flesh, and the short duration of its life, electric tramways had proved economical and very successful. They had proved a great financial success, for, owing to the smoothness with which the trains ran, they had greatly increased the comfort of travelling, although they ran between the same points and on the same rails. This comfort of travelling by the electric trains had increased the traffic 30 per cent., so that, for no other reason whatever than the introduction of electricity, they had introduced what the Americans called, in their practical way, a "factor of public satisfaction." The practical feature in which members would be perhaps more interested, was that the trains were almost all worked by wires overhead, on what was called the trolley system. That system, on a small scale, had been introduced in Leeds, and also in the Staffordshire district, in the neighbourhood of Walsall, but its development in England was small compared with that in the United States. There it was seen not only in all the suburbs of the cities, but also in the great cities themselves; and anything more, horrible had never been seen in this world than those wires

extending through a beautiful city like Boston, simply covering Mr. Preece. the principal thoroughfare with a cobweb of a diameter of about $\frac{1}{8}$ inch to $\frac{1}{4}$ inch. The great problem now being solved in the States was how to work those railways by an underground system, and how to get rid of the disturbances arising through the use of the earth. That problem had been solved at Washington and Chicago, and probably in a year or two someone would come forward to give the results of those experiments. The only railway in the States which would compare with the magnificent railway described by the Authors was one that extended through the midst of the World's Fair at Chicago, called the Intramural Railway; and to give an idea of the extent and size of the Exhibition, that railway, which had been constructed simply to carry visitors round and about the various buildings, was $3\frac{1}{2}$ miles in extent. It worked extremely well. It was very like the Liverpool Overhead Railway; it had a third rail, not in the centre, but by its side, and the rails were used for the return. Twelve trains were constantly running without accident or trouble, and it was a comfort to be thus able to move about from place to place in the Great Fair by that charming railway. Another feature worth noting in the United States was that experience had shown that they had commenced with too light rails in the early days, rails of about 30 lbs. to 35 lbs. weight per yard having been thought satisfactory. These had been gradually increased. The Intramural Railway had been constructed with rails weighing 60 lbs. per yard; several lines had been constructed with 72-lb. rails, and he was told there were one or two railways where they had even gone to the extent of using rails weighing 90 lbs. per yard; finding that, by using those heavy rails, the cars ran more smoothly, and there were none of those jars and jolts and discomforts that interfered so much with the working of motors and electrical appliances. Again, the Americans were fast following the English example of direct-driving in their power-houses. He found one single fault, and only one, and that perhaps a personal one, in the system adopted in connection with the Liverpool railway, viz., that the general practice in this country of using direct-driven machinery had been abandoned for the use of rope-driven apparatus, which he thought was a slight survival of the past. In the States many power-houses were found where rope-driven machinery was the rule; but, on the other hand, in all modern stations and all new work, the system which had been found so much better in England, of using direct-driven machinery, was being adopted. He thought, on the whole, after

Mr. Preece. a most careful examination of what had been done in the States, that the Authors had unquestionably taken a great step in advance at Liverpool. There was nothing in the States that was superior to, and he did not know anything that was as good as, the working of the railway described. One feature referred to in the first Paper deserved to be brought strongly under notice, viz., in Table B, it was shown from experience that the tractive-force in pounds per ton of motor or locomotive was, for the electrical system in the Liverpool Overhead Railway, 730 lbs. per ton, and on the City and South London Railway, 367 lbs. per ton; so that, in the short period between the construction of the two lines, the same engineer, by the advance which had been made in electricity, had been able to increase the tractive-force nearly 100 per cent. Going to the Metropolitan District Railway, it was found that the tractive-force per ton of the locomotives was only 234 lbs.; so that the difference between the traction per ton on the District Railway and that on the Liverpool Overhead Railway was the difference between 234 lbs. and 730 lbs. That was an advance of which English engineers might be very proud. The most important feature brought out in the Paper was the economy of electrical traction. He had more than once pointed out in that room that the economy of electrical traction and the production of electrical energy was entirely dependent on the ability to maintain a full and constant load. Whenever a revolutionary doctrine was enunciated, even though it might be the truth, it was always received with ridicule by those whose interests were affected; and when he asserted, as he had done in that hall, that, if he had the means of producing electrical energy constantly and continuously at a full load for twenty-four hours, electric light could be produced at a price equivalent to gas at 2*d.* per 1,000 cubic feet, he had been laughed to scorn. The engineers of the Overhead Railway had shown that, although they had not a load continuous for twenty-four hours, they had one continuous for nearly twelve hours, and the diagram showed that the mean load throughout the day was fairly constant. The Author of the second Paper had shown that the cost of working that line was 4*d.* per train-mile, and hence the cost of production of electrical energy to maintain the traffic on the railway was equivalent to $\frac{8}{10}$ *d.* per mile, and $\frac{8}{10}$ *d.* per mile was not far short of gas at 5*d.* per 1,000 cubic feet; that was, if the energy used for working the trains were used for generating light. The results of the experiments on the Overhead Railway showed that the figures he had given were approximately true, and also that the

secret of working electrical appliances, whether for light, for Mr. Precece. traction, or any other purpose, was to maintain continuously as long as possible a full load, and to maintain the machinery at its maximum working. The fact had been mentioned that the leakage on the railway at Liverpool was a mere 2 or 3 amperes, and that such an unnecessary refinement as using oil to reduce this was absurd. There was a marked amount of selfishness about that. It might be perfectly true that the Liverpool Railway could afford to lose 2 amperes or 3 amperes, but there were persons in Liverpool, and interested persons, who could not admit that the absorption by the earth of 2 or 3 amperes was a refinement. The Postmaster-General did not like to find, as was found, that every single circuit in Liverpool was disturbed by the elevated railway. It was perfectly true that he was very good-natured, and had not applied to the Court of Queen's Bench for an injunction to stop this railway; but if its managers allowed the 2 or 3 amperes to become 20 or 30 amperes, it might be they would find some day an application by the Postmaster-General to the Lord Chief Justice to stop the traffic on that railway. But it was not alone the Postmaster-General who had an interest in stopping the leakage, for how about the gas people?—how about the water people? One of the most striking features brought to his notice in the States was the terrible havoc committed amongst gas-pipes, which were riddled and pitted all over, and water-pipes which were corroded and destroyed, whilst the lead coverings of the telephone-cables were absolutely a decayed mass through this refinement, or absence of refinement—not a leakage of 2 or 3 amperes, as at Liverpool, but a leakage amounting to 200 or 300 amperes. If those gentlemen did not look after the pennies, they might depend upon it the pounds would bring them into very serious difficulties. There were several problems that were unsolved. It might be taken as a fact that where there was great diversity in practice, perfection had not been attained, and there was great diversity of practice in electrical railways. It was not yet determined which was the best mode to work electric railways, whether by alternating currents at low frequency, or by the continuous current as at Liverpool and on the City and South London and Chicago railways. Again, practical men who had to look to pounds, shillings, and pence, were not satisfied with the means at present developed in starting trains. With a steam-locomotive, a train was started without loss of energy, but on an electric railway, the train was started with a considerable loss of energy, and the great waste of

Mr. Preece. energy occurred at the moment the train was starting. Someone would have to produce a remedy, and he was sure that if Mr. Thomas Parker devoted his attention to it he would introduce some means by which to start the electric train without any useless loss of energy. The Americans, he was proud to say, paid great heed to what was being done in this country. They thought, no doubt, we were a grandmotherly lot, and were very slow, but they all admitted that we had adopted a thoroughness and a refinement in our methods that it was necessary for them to follow. Doubtless the Paper now brought forward would be read and studied in America with great interest. Sir Douglas Fox had stated that the Dock Board were so particular about fires that they would not allow a man to smoke. But they would not also allow locomotives because they emitted sparks, and therefore electric traction was introduced. Mr. Preece did not know whether Sir Douglas Fox laboured under the illusion that electrical machinery could always be worked without producing sparks. One of his amusements in the States was to watch the electrical railway at night, for a more beautiful display of fireworks he had rarely seen. If Sir Douglas Fox was satisfied with the absence of sparks on the Liverpool railway, then something or other must have been done on that railway which had not been described in the Paper. He hoped that when Mr. Parker replied he would give some explanation as to how sparks were stopped in Liverpool. The Authors had said that the Americans in New York studied very carefully the application of electricity to elevated railways, and had given facts and figures showing that the cost of applying machinery to the Elevated Railway was estimated at £771,000. The Authors had, however, shown that the cost of the plant on the Liverpool railway of the same length and character was only £45,000, or only five per cent. of the estimated cost of the Elevated Railway in New York. Again the engineers at New York made out the cost of working the Elevated Railway to be 3s. per train-mile, but now the fact was on paper, that not only was tractive power greater than that produced by steam obtained, but a magnificent railway was worked in first-rate style, giving satisfaction to everybody, at the small rate of 4d. per train-mile.

Mr. Cottrell. Mr. S. B. COTTRELL did not think he could add anything to the general description of the railway, but having had it under his observation during the first twelve months of its working, he might mention one or two points of interest. As had been stated, the only serious damage to the structure during the period mentioned

was caused by fire. The conductor as laid, had flexible copper connections at each joint, and as a result, a very considerable amount of creeping took place. The conductor was now coupled in lengths of 90 feet with rigid copper fish-plates, flexible expansion-joints being introduced at every third length; the creeping had entirely ceased and the conductor could be kept in very good line and level, whereas before, foul joints continually occurred, and it was difficult to keep the conductor in line and level. During the first month or two short circuits occurred frequently, but now they very seldom happened; in fact, there had only been 19 since the beginning of 1894, each one of which was caused by the collecting-slippers touching the running rails when going through a cross-over road. The motors had come well up to the workshop tests. Only two of the whole number had required re-winding, and even then about 80 per cent. of the old coils were re-used. At first there was some little trouble with the brushes, the commutators frequently requiring to be skimmed up, but by a modification of the brush-holder that had been very much reduced. Originally the commutators required skimming up after running about 6,000 miles, but now they would run 9,500 miles, and one had run 16,000 miles without skimming. The carbon brushes cost at first about £6 per week. That had been already reduced to £2 10s., and it was hoped shortly to get it to £1 per week. The brushes used were flat carbon ones; round carbons had been tried and also copper gauze, but without success. The stations, as described, were lighted from accumulators, but during the winter months the accumulators were worked at very nearly their maximum output, in order to increase the life of the batteries; arrangements had therefore been made for lighting the stations by means of two sets of lamps, one in series off the main conductor, the other in parallel off the accumulators. An automatic switch was arranged so that, should a short circuit occur, the lights were automatically switched on to the accumulators. Of course that meant some slight fluctuation in the light, but it was so trivial that it did not matter. The automatic signals were a new departure, but had answered admirably, effecting a very considerable saving in the working expenses. In the six months ending the 31st of December, the failure of signals to go to danger and to come off was 1 in 24,000 and 1 in 1,200 operations respectively. In the two months ending the 28th of February the signals had so much improved in working that failures were 1 in 212,000 and 1 in 2,000 operations; the cause of these failures in most cases being not electrical but mechanical. During the last two

Mr. Cottrell.

Mr. Cottrell. months he had gone very carefully into the cost of haulage, that was, since the Electric Construction Corporation had handed it over to his Company. With coal at the present price of 8s. 3d. per ton the haulage worked out at 3·48d. per train-mile. With coal at its normal rate, as at the corresponding time last year, of 6s. per ton, it would only be 3·34d. per train-mile. Those figures included all wages, stores, etc., or, in other words, what came under the term of locomotive expenses. He entirely agreed with Sir Douglas Fox that for a traffic like that at Liverpool short trains at frequent intervals was the best system. Last August Bank Holiday 40,000 passengers were carried in about eight hours, and the platforms were never overcrowded. That was done by a three-minutes' service of trains, and he had reason to hope that a three-minutes' service would soon be required to deal with the regular daily traffic.

Mr. Siemens. Mr. ALEXANDER SIEMENS noticed that several speakers had mentioned that it was a great advantage to have the motors on the cars, and not a separate locomotive. That matter had to be decided in each case on its particular merits; it could not possibly be universally true that a locomotive was the best, or that motors on the cars were the best. He might illustrate this by referring to Table A in the first Paper, where a comparison was given between the weights of motors and locomotives, which came out very much in favour of the motor system adopted in Liverpool. There were only two carriages, and, of course, the arrangements for working the two motors on the carriages from the one end or the other were comparatively simple. But the moment a railway was dealt with, where more carriages were wanted to run at the same time, the question of the switching-arrangement was very serious. He did not know whether in most cases it would not preclude the use of motors on the carriages. In the same way, the multiplication of small motors on all the carriages meant a serious increase in cost, which, of course, was also not to be solved generally, but each case must be looked into. For instance, in Table A, the electric motors of the South London Railway, which had been made by his firm, did not weigh 10½ tons, but 13½ tons; they were 3 tons heavier than those of the Liverpool railway. On the other hand, those locomotives were powerful enough to draw at least two more carriages easily; though it could not be done on account of the accommodation for shunting in the City being insufficient. But supposing that five carriages were put on instead of three, the total weight of the train would be 45 tons, and the weight of the full train would be 802 lbs. per passenger against

871 lbs. in the Table, and against 752 lbs. for the Liverpool Over- Mr. Siemens.
head Railway. If the electric locomotives were properly used and fully utilized, the discrepancy was not so great as appeared in Table A of the first Paper. In Table B the "tractive-force in lbs. per ton of train" was given as 120 for the 150-ampere motor on the Liverpool trains, and as 100 on the City and South London train. He wished to contrast that with the figures given by Mr. Preece, who stated that the locomotive at the Chicago Exhibition was giving a 6000-lb. pull, and was meant for a 500-ton train. That was 12 lbs. per ton of train. Mr. Siemens had also been at Chicago. He did not see the actual trial of the locomotive, but the company were kind enough to give him some information; and, among other things, it was stated that the locomotive was capable of developing 500 brake-horse-power at 30 miles per hour. As they proposed working with 500 volts, that would amount at least to 750 amperes of current. That was the mere electrical horse-power, no allowance being made for loss in friction or from other causes. To supply that current to the locomotive, there was a single rod with an ordinary trolley-wheel, but he was certain if 750 amperes ever attempted to get through those trolley-wires the trolley-wheels would melt away in no time. Great caution must therefore be exercised as to the importance to be attached to the figures given. It had been already pointed out by Mr. Preece why the experiments on the Elevated Railway in New York had failed. Mr. Siemens had had similar experience with that line. His firm, in 1881, offered to run one of the short lines by electricity, fitting up the line at their own expense, on the condition that, if it worked properly, they should have the fitting out of the whole system. It did not, however, suit the Stock Exchange in New York, and the offer was not accepted. Similar reasons appeared to have prevented the success of the experiments actually carried out. He was sorry to know that in the Liverpool power-station the dynamos were driven by ropes instead of direct. He thought that double limb magnets were also a retrogression. There had been plenty of experience in 1885 of dynamos with double limb magnets of about the same size, and it was found that the horse-shoe magnet type was preferable in every way. In reference to experiments with ordinary drum-winding on the car, the Author of the second Paper had stated that he found that the Eickemeyer winding was better. Mr. Siemens had wanted some idea as to how the motors of the two locomotives which their firm supplied to the City of London, acted, and he had received a letter from Mr. Mott, the resident engineer, stating—

Mr. Siemens. "I have pleasure in sending you the following information, as requested—

					Miles.
"1.	Loco. No. 16.	Total mileage to January 28th, 1894	.	.	59,221
	Loco. No. 15.	do.	do.	do.	49,580

"2. It has never been necessary to make any considerable repairs to these locomotives, except the alteration to the resistances which is now being done."

The second locomotive was delivered later than the other, hence the difference in the mileage. He did not believe there was a steam-locomotive which had run close upon 60,000 miles without any repairs or alterations. The expense of brushes had been said by Mr. Cottrell to be £2 per week, but one of these locomotives had run with the same pair of brushes since it was delivered. He was rather astonished to hear Mr. Preece speak of hideous overhead-wire and disparage it. He was always under the impression that the telegraphic wires were the great eyesore, and that if a line was properly put up, as, for instance, in South Staffordshire, it certainly was not such a frightful eyesore as Mr. Preece had tried to make out. Mr. Preece had also touched upon a point which he was afraid was greatly misunderstood. He had said that 2 amperes might career about Liverpool, eating away gas- and water-pipes. It was not the amperes that did anything. The possibility of pipes being damaged depended upon the pressure under which those amperes were sent about. If the difference of potential between the end of the line and the power-house was only 2 or 3 volts, 200 or 300 amperes might be about, and they would not damage a pipe. Of course they would interfere with telegraphs and telephones, but they could not do any damage to the pipes.

A great point was to be able to start an electric locomotive with less loss of energy than under the present system, where resistance was inserted at first, or other means were adopted; and he would suggest that a very good way, although it might not seem to be so at first, was to put on the locomotive a motor generator, and supply a high-pressure current from the power-house at 2,000 volts to the generator, and to put motors on the axles of the locomotive. That system, taking into consideration the cost of the conductors, the extra cost of the motor generator set, was not very much more expensive in capital outlay than the present plan of supplying a 500-volt current direct to the locomotive; but it did introduce additional complication; and, putting the whole arrangement into £ s. d., it would be found that the present system, although wasting a good deal of energy at the starting of the locomotive, was preferable, because it was

simpler. He thought it was probably necessary to re-assure the Mr. Siemens.
 Dock Board about the sparks of the electric railway—that they were not of the same nature as sparks from a locomotive, where particles of carbon were flying about, which constituted a real danger to any inflammable substance that might be near. The sparks of an electric railway occurred near the rails, and were, of course, only particles of iron, which could not fly any great distance, and there was absolutely no danger whatever from them. Then there was a further interesting question touched upon by the Author of the second Paper, who wished it to be believed that the mean efficiency from I.H.P. to electrical H.P. on full load was 88 per cent. Only a few weeks ago, certain figures had been published about a direct-driven set which gave similar efficiencies, and they were promptly denied by “one who knew,” who said that such efficiencies in steam-engines and dynamos were simply impossible; and he certainly thought that, with the addition of the rope-driving, 88 per cent. was too high. On the other hand, he thought that, in the trial detailed, the Author had hardly done himself justice, because if the figures given were compared with those which were attained on the City and South London Railway, and communicated to the British Association in 1892, it would be found that the average speed, including stops, which for the Overhead Railway was given as 12·3 miles per hour, was nearly 13 miles per hour on the City and South London. Then the average watts per train-mile, the trains being about the same weight, were given in the Paper as 32,650; whereas on the City and South London line only 21,320 watts were used per train-mile, which was a very great difference. He was sure there must be some mistake, because he could not imagine that the motors of the Liverpool line were so very much less efficient than those of the City and South London Railway. The great point for electrical traction was to have a frequent service. That was what had been pointed out as the reason why the average curves were much smoother the greater the number of trains there were; and, generally speaking, it could be laid down that where an electrical service was to be introduced on any line there ought to be frequent service; it was perfectly impossible to introduce electrical traction satisfactorily on railways where there were only three or four trains a day.

Mr. R. W. BLACKWELL had built that first road in America to Mr. Blackwell.
 which Mr. Preece had referred, in 1884, and during the succeeding years, as electrical traction progressed, had to meet all those objections which had been mentioned with regard to the overhead wire. Ignoring other questions, he would like to say a

Mr. Blackwell. word in that regard. In America, between 1883 and 1890, it was said by every city, by every electrical company, by every tramway-engineer, and by every æsthete, that an overhead line in a street was an abomination never to be tolerated, and should never be allowed under any circumstances. The consequence was that the pioneers of electrical traction in America began their work with the idea of perfecting the conduit system, which could be worked without the use of a visible conductor. They effected that result, and, when they did so, the cars ran fairly well; but when the question came to the financial test, and to the test of regular work, it was found that it cost approximately £7,000 a mile to put in a more or less efficient underground conductor, and that it cost about £700 a mile to put a first-rate, practicable conductor overhead. The reason why the overhead conductor had been adopted in the States had been simply that financial and practical reason. He thought everyone believed it was possible to make an underground conductor that would work; but nowhere had it, to the best of his knowledge, been made anything like a financial success, with the possible exception of that at Budapest. On the other hand, he believed it was absolutely demonstrated to the extent of some £30,000,000 invested in electric tramways in the United States, that every overhead trolley-wire that had been erected had proved a financial success, had increased the dividends, and had served the purpose of the public in increased and more rapid transit. In the earlier days of electric traction elevated conductors were undoubtedly rude and unsightly in many cases, but so much attention had been paid to the elaboration and perfection of details of suspension and insulation that the trolley-line of to-day was quite another thing. It seemed to him that such objections as might be urged against the aerial wire were vastly less important than those which were connected with any system that involved interference with the street surface and the maintenance of an open slot. Many great continental cities had lately adopted the trolley system, and from a personal inspection of lines in Bremen, Hamburg, Brussels, Frankfort and other towns, he was convinced that the method of construction there adopted left little to be desired.

Mr. Sellon. Mr. STEPHEN SELLON thought there was no necessity to go so far as the Niagara Railway in order to find a gradient of 1 in 20. There were plenty of tramways working at that gradient; for example, the electrical tramways in South Staffordshire and at Leeds, and the City and South London Railway. Referring to the abomination of the wires over the streets in Boston and other

places, which made the overhead system so objectionable, the overhead wiring had been much modified to meet English ideas, and very little objection could be raised by anybody viewing the system as applied on the electric tramway in South Staffordshire,¹ from a public road. In the American system, the trolley-arm worked from the centre of the car, which had no lateral movement; and therefore the conductor over the centre of the line was necessary. A large number of pull-over- and span-wires had to be used for this purpose. In South Staffordshire a different kind of trolley-arm was adopted, having a radial motion enabling the conductor to be placed on a single row of poles alongside the road, dispensing altogether with any span or pull-over wires. The overhead system as there adopted showed a marked improvement upon the American principle; and it was not fair that the system should be condemned because in America an act of vandalism was committed in its application. Looking at the question of economy, he thought it would be absurd to suggest a conduit system in a district where it could not pay. Overhead installations, therefore, became necessary; and, no doubt, engineers in this country were quite able to reduce the objections, and not necessarily to have the overhead system as it was found in America. The remarks coming from Mr. Preece, the Chief Engineer to the Post Office, in objecting to the overhead system were somewhat extraordinary, as in Mr. Sellon's opinion it was no more objectionable to put up a few overhead wires, than it was to put up the usual structures of poles and innumerable wires that were seen along the whole of the roads in the country. It might be interesting to give a few figures in connection with the South Staffordshire tramways system, which was originally worked by steam, and of which 8 miles were, in 1892, equipped with the overhead electric installation. While the line was working by steam, the gross earnings per car-mile reached the sum of 1s. 1½d., and the cost of working per car-mile was 1s., leaving a very short margin of profit. On the introduction of electrical traction in 1893, working expenses were reduced to 50 per cent. of the gross receipts. Referring again to Mr. Preece's remarks, that important body, the Joint Committee on Electric Powers Protective Clauses, had decided that railway companies, telephone companies, and gas and water companies should be called upon to protect themselves, so long as certain reasonable regulations (which regulations were not to place any

¹ A description of the South Staffordshire Electric Tramway is given in Section II. of this Volume.

Mr. Sellon. restrictions on the commercial working of electric traction) were complied with; and from past experience, he was sure that any serious conflict between the Post Office and any electrical traction installation, by which the Post Office might seek an injunction to stop the working of a tramway, would be due to the fact that the latter had not responded to the reasonable requirements nor to the well-known courtesy of the Chief Engineer to the Post Office. In conclusion, he would venture to express the opinion that the successful completion of the unique work described in the Paper was due to the fact that mere electrical theorists had had no part in the matter.

Mr. McDONNELL. Mr. ALEXANDER McDONNELL was acquainted with the South Staffordshire tramways, and could see nothing, so far as the wires were concerned, in the least objectionable there. In the Paper, a comparison had been made between trains on the Liverpool Overhead Railway and on the Metropolitan Railway. Unfortunately the word "train-mile" was used a little too loosely. A train-mile, when comparing the expenses of one railway with another of similar traffic, or the expenses of the same line one year with another, was exceedingly useful—not perfect by any means, but still of very good practical use; but to compare a train weighing 38 tons and carrying 115 passengers with another train weighing 157 tons and carrying 400 passengers, was going too far. The system of electrical traction upon the Liverpool Overhead Railway was exceedingly well adapted for the trains and traffic there; but for such a line as the District or the Metropolitan Railway, with the traffic on them, it would be found that it was not adapted in any way, so far as was known at present. Where there was a system of trains running at intervals of three to four minutes, electric traction was tolerably economical; and, taking the District system, where between the Mansion House and Victoria there was a three- or four-minute service, supposing the electric traction was sufficiently powerful to deal with a train of 150 tons, there might be economy; but when places like Wimbledon, Ealing, Willesden and Richmond were considered, where there was a half-hourly service of trains, it certainly would not be economical. Electric traction seemed very good where there was a fairly developed traffic of light trains running very often; but it certainly was not at all suitable for developing traffic on a railway of light traffic. In the case of a tramway, traffic must be developed by horse traction or locomotive traction, and when it was developed electric traction might be useful; but to lay down the whole of an electric system, with its fixed plant, for a tramway system with cars

running every twenty or thirty minutes would certainly not be economical, although it might be economical in a three- or four-minute service. It was stated that the locomotives on the overhead system in New York burned 54 lbs. of coal per train-mile for trains of about 92 tons weight. Upon an ordinary branch-line, a train would have about five carriages weighing about 50 tons, and a tank-locomotive of probably about 45 tons, making 95 tons altogether. Such a train would seat about 200 passengers if full, which, of course, it never was. A locomotive would work that for about 18 lbs. of coal a mile, so that 54 lbs. was to him quite unintelligible. The cost of working such a train by locomotive power would be about 6*d.* a mile. It was stated that the electric traction cost about 4*d.* a mile when the trains were run frequently; but the Authors had omitted to take into account the depreciation and renewal of stock. The 6*d.* a mile that Mr. McDonnell was speaking about included everything—drivers, coals, ordinary repairs and renewals. He expected that in electric traction the depreciation would be considerable—that the life of a great part of the stock would be very short. Of course the life of the fixed plant, stationary engines and so on, would be long; but the motors and things of that sort would in all probability be short-lived, and to that 4*d.* a mile the depreciation should be added. To suppose for one moment that, because the electric system was good and economical upon a railway such as that described in the Paper, it could be used for anything like an ordinary railway system was quite beyond his comprehension. For a railway such as the London and North-Western, with trains varying between 80 tons and 500 tons in weight, and with speeds varying between 20 miles and 60 miles an hour, the system was not adapted, and any kind of comparison made between them could not be fair. Without in any way suggesting that the system adopted on the Overhead Railway at Liverpool was not exceedingly well adapted there, he considered that it was not at present suitable for other railways, not even the most similar in kind—namely, the Metropolitan.

Mr. W. WORBY BEAUMONT wished, first, to ask the Authors if there was any reason other than that stated in the Paper, why the plates forming the flooring of the viaduct were bent hot, and if they could not have been put in cold. He was under the impression that a machine might have been made at no great cost which would have bent the plates cold at a low cost compared with the expenditure in bending them hot. Another point was the one on which Mr. Trotter had remarked, with refer-

Mr. Beaumont. once particularly to some of the diagrams. It was known that for the working of any set of machinery, or for any electrical installation, the load-factor might be said to give an indication of the expenses and of the profit that might be obtained at any particular time. The diagrams shown accentuated the remarks, he thought, made by Mr. Greathead on previous occasions as to the great cost at present incurred in getting a train into motion electrically and also in shunting operations, as, for instance, on the City and South London Railway. He thought it might be shown that to a very large extent that waste might be avoided. Taking a datum line as in the diagrams given in the Proceedings Inst. C.E., vol. cxii., pp. 246, 247, it was found in almost all cases that the diagram representing the power taken in getting an electrically moved train into motion was of the character referred to by Mr. Trotter. As soon as the train had fairly started, the time occupied being, as shown by some of the diagrams, only from ten to fifteen seconds, the power taken fell to about one-half; it was of various heights further on until a stop was reached, and again this was repeated. It was not only that the power as compared with that taken by the steam-locomotive to get the train into motion was, for the greater part, waste power, but it meant that the power which must be available at the central-station must be that represented by the full height of the power diagram. It was not that a mean load had to be available, but that at any moment the power represented by that full height must be available, the engines running for that purpose. Of course, the power was not always used, and the engines, and particularly the boilers, were working at a great disadvantage; because, although that power was not taken, it must be ready to be supplied at any moment. He had shown on a previous occasion that it would be possible by mechanical means to avoid taking more power than was necessary for keeping the train in motion. Mr. Siemens had mentioned a method of getting over that difficulty electrically, and had explained why it was bad or insufficient; and having proved that it was not satisfactory, had said it was better to waste the small amount of power shown between the two lines midway on the top of that diagram, rather than to use a method which he had said was not a good one. That, therefore, could hardly be said to have been of assistance with regard to this problem; and although on several occasions it had been mentioned that electrical methods might be adopted, it had not, he believed, been shown that electrical methods could be used which would avoid the necessity for a great deal more power than would be required by a locomotive engine in moving

its train. As Mr. Trotter had pointed out, until a train was actually in motion, or so long as the locomotive-engine was getting it into motion, it was actually doing little work, and the steam was only used in that degree. To get over the difficulty, two motors might be coupled as on the Elevated Railway, in series, getting the train more rapidly into motion and avoiding some of the electrical difficulties that would otherwise occur; but, at the same time, the power required for getting the train into motion within a given time was just as great as if the motors were in parallel. As far as was yet known, electrical methods could not be said to be satisfactory for surmounting that difficulty; but it could be got over mechanically, and it only remained for engineers to adopt the methods that had previously been pointed out.

Dr. EDWARD HOPKINSON, in offering a few criticisms upon the second Paper, did not wish it to be supposed for a moment that his object was to detract from the excellent results achieved. Those results were most striking, but, at the same time, some statements had been made which appeared to him to be open to very serious exception. With regard to the question of efficiency of engines and dynamos at the generating-station, the Author had given the electrical efficiency of the generating dynamos as 97·7 per cent. That, no doubt, could be attained in well-constructed machines, and fairly represented the electrical efficiency at Liverpool. But the Author had gone on to say that the efficiency, as between the I.H.P. in the cylinders of the steam-engines and the electrical HP. as delivered from the terminals of the dynamos, was 88 per cent. Anyone who had experience of the frictional diagrams of large steam-engines, and especially the friction caused by rope-driving, would recognise in that a very startling result, and one that he was not at all prepared to accept. Perhaps the highest efficiency ever realised as between electrical HP. and I.H.P. had been obtained with a Willans engine. Everyone who was familiar with that engine would state, from the perfection of workmanship exhibited, that the friction must be exceedingly low; and yet the best results ever obtained by Mr. Willans with a great variety of dynamos by the best known makers had never exceeded 87 per cent. The efficiency was usually 85 to 87 per cent., and the few results obtained above 86 per cent. were, it would be admitted, probably due to the fortuitous concurrence of various small sources of error, which happened to run together in a favourable direction. Taking the Author's figure of 88 per cent., and the electrical efficiency at 97·7 per cent., it meant the loss in friction of engine, ropes and dynamo, and by

Dr. Hopkinson. electrical friction of various kinds in the armature, was only 10 per cent. Such a result, all who had any experience of rope-driving, would at once say was absolutely impossible; in fact, before it could be accepted, the Author would naturally be asked to give the friction-diagrams of engines only, the friction-diagrams of engines and ropes, and finally the friction-diagrams of engines and dynamos running without load. The motors were, no doubt, the most important and the most difficult point to deal with in traction work. The armature-resistance of each motor was given as 0·67 ohm and the magnet-resistance as 0·37 ohm, making a total of 1·04 ohm. When the motors were in series, as at starting, the current was about 130 amperes. Doubling the resistance for two motors the result was 2·08 ohms, which, multiplied by 130, gave the loss in volts at 270. Therefore, the electrical efficiency of the motors throughout the early part of the run up to the point at which the two motors were placed in parallel, was 44 per cent.; after they were placed in parallel, with a current of 90 amperes, the efficiency was of course improved, but still did not reach more than 80 per cent. He was very far from saying—in fact, quite the reverse—that the Author had been wrong in designing the motor with a large number of convolutions on the armature in order to have a very high resistance and consequently exceedingly low electrical efficiency with a heavy load. It was known that if the spare electromotive force at starting was not absorbed in the armature and the magnet coils it must be absorbed in the external resistance. He mentioned this simply to draw attention to the fact that these motors at that period of their running had this extremely low efficiency, and to show the direction in which better results might be obtained in the future. In remarking upon a Paper¹ which Dr. E. Hopkinson had read before the Institution last year, the Author had given the resistance of the City and South London motors at figures about one-third the resistance of the Liverpool Overhead Railway motors. Their power was about the same, but the Author, by putting more convolutions on, absorbed the power in the motors instead of in the external resistance. To effect that, the device of putting the motors first in series and afterwards in parallel had been adopted. In that the Author had done right; but it would only have been proper on his part if he had acknowledged to whom that device was due. It was due, as a matter of fact, to Dr. John Hopkinson, but had been taken up by the late Sir William Siemens more than

¹ Minutes of Proceedings Inst. C.E., vol. cxii. pp. 209 *et seq.*

ten years ago. Here, again, it was matter of regret that the Dr. Hopkinson Author, in describing the motors, and especially the system of direct driving, should not have thought it necessary to refer to what had been done previously in that direction, and more particularly to the work of the late Sir William Siemens. Electrical engineers had not advanced so far in traction work that they could yet afford to ignore the pregnant suggestions made by Sir William Siemens at a time when the subject was in its infancy. For the same reason, he would notice that the form of conductor and the method of supporting and insulating it were exactly the same as had been adopted on the City and South London Railway; but of that he had no reason to complain, as imitation was not uncomplimentary. The most important point in the Paper was the statement that the tractive force of each motor was 1,450 lbs. with 100 amperes. In discussing Dr. E. Hopkinson's Paper last year, the Author had given 1,450 lbs. as the tractive force of two motors. [Mr. PARKER: One motor.] Taking the figures as applying to one motor and following out the results, if the Author had given the number of convolutions of the armature and the number of lines of force, not through the magnet but through the armature, the tractive force with any current could be at once determined; but this he had not done, and the result must be judged by the subsequent part of the Paper. It appeared, as far as could be judged from the small-scale diagrams appended to the Paper, that the mean current during the time of running was 110 amperes; that for one-fifth of the time the current was 100 amperes with the motors in series; for three-fifths of the time it was 150 amperes with the motors in parallel; and for one-fifth of the time it was cut off altogether; thus giving the mean current 110 amperes while the current was on, which agreed with the Author's result of 90 amperes while running. Taking the curve of tractive force and current and deducing therefrom the tractive force corresponding with the currents given in the Paper, this extraordinary result followed; that the average tractive force per ton of train was 55 lbs. It had been ascertained that on the City and South London Railway the average tractive force was 13 lbs. per ton of train. There was therefore the extraordinary discrepancy between 13 lbs. and 55 lbs. per ton for trains weighing practically the same, and working under much the same conditions. From the work done by this 55 lbs. per ton of tractive force, must be deducted the energy which was required to give the train its velocity. The total amount of work done in one section of the line of average length was 3,521,000 foot-pounds, and the energy required to

Dr. Hopkinson. give a train of 39 tons a velocity of 21 miles per hour was 1,295,000 foot-pounds. Hence, deducting this amount, which of course it was proper to do, the final result was that the tractive force required to work the trains on the Liverpool Overhead Railway was 35 lbs. per ton, *i.e.*, the force required to overcome the resistance only and not to give the train acceleration. That was a result much more than double the figure previously given for the City and South London Railway, and also greatly in excess of common experience. There were therefore good grounds for expressing the opinion that the Author had made the mistake of confusing the tractive force of one motor and of two motors; and that affected the comparison instituted by Mr. Greathead and by Sir Douglas Fox between electric and steam traction.

All systems of traction must be finally judged by the cost at which the service required was provided, and in that respect excellent results had been obtained at Liverpool. It was interesting to observe that, when local circumstances were taken into account, the results were almost identical with those obtained on the City and South London line as ascertained from the balance sheet for the half-year ending December 31, 1893. The weight of the trains and the speeds attained were about the same, but on the City and South London line there were somewhat steeper gradients and sharper curves, and the railway was in tunnels; on the other hand, at Liverpool there were somewhat more frequent stops. The total cost of traction on the Liverpool Overhead line, including current supplied for signalling and lighting, was 3·975*d.* per mile, with coal at about 55·10*d.* per ton; whereas, on the City and South London line, including current for lighting but not signalling, it was 6·22*d.* per train-mile with coal at about three times the price for the same calorific value, and a higher rate of wages obtaining. If the coal in the two cases had cost the same, the City and South London cost would have been 4·9*d.* per train-mile. It might, therefore, be taken as proved beyond doubt that such railways could be worked electrically at a cost for motive power of 4*d.* to 6*d.* per train-mile according to the price of coal. But these results would undoubtedly be further improved upon in the future. On the Liverpool Overhead line the repairs amounted to 0·95*d.* per train-mile, whereas on the City and South London line, which had the advantage of having been working for three years, and therefore was in all its parts thoroughly well tested, the cost of repairs of all descriptions was only 0·7*d.* per train-mile; in fact, he had been recently informed by the engineer of the railway that many of the locomotives had now run over 100,000 miles, and that

the cost of repairs upon them during the last 30,000 miles had not Dr. Hopkinson. exceeded 0·03*d.* per train-mile.

Mr. T. PARKER, in reply to the discussion, referring to Mr. Mr. Parker. Hedges' remarks on the Niagara Falls Electric Railway, compared it with the overhead wire system of tramways in South Staffordshire. On the latter line, the gradients reached as high as 1 in 16, sharp curves occurring upon some of them. The cost of working this system (each car carrying 34 passengers, being equipped with two motors, and weighing without passengers about $6\frac{3}{4}$ tons), during the six months ending December 31, 1893, including car-drivers' wages, maintenance of generating-plant, car-motors, feeders, trolley-wires and superintendence, was 4·16*d.* per car-mile. In the case of the Blackpool tramways, for which the Author designed the dynamos and motors, the cost of running during the year 1891 amounted to $3\frac{3}{4}$ *d.* per car-mile, this amount including costs usually charged to haulage, but exclusive of traffic expenses, repairs to permanent-way and general management expenses. It had many mechanical and electrical defects in the method of conveying and collecting the current. In the Madras Tramways with which he was now engaged, the slot was not in the centre of the road as at Blackpool, but in the groove of one of the rails, and $\frac{3}{4}$ inch wide. The difficulty of securing satisfactory collection from underneath the road through the slot and past the points, had previously prevented that mode of slot from being brought into use, but he had now surmounted those difficulties, at a cost of about £1,600 per mile over ordinary road.

The great amount of power required in starting the trains on the City and South London line had been pointed out by Mr. Trotter, and upon that point he would refer him to Figs. 13 and 14, Plate 5, which showed that the trains at Liverpool required less energy at starting than when in motion, and the advantage of placing motors in series for starting and afterwards in parallel. Attention had been directed by Mr. Preece to the rope-driving used at Liverpool, and in reply to his remarks, Mr. Parker could only state that he had most careful tests carried out, and had submitted them to the Institution in all good faith. The data used in comparing those tests was taken chiefly from high-speed engines and direct driving; and there was no definite proof that high-speed rapidly-reciprocating engines did not absorb as much power in arresting and accelerating their parts as was required to drive ropes arranged as at Liverpool. With regard to electrical leakage, the Liverpool Overhead Railway was very favourably situated, as the iron structure afforded an easy return for straying currents. The point to

Mr. Parker, be considered was whether the progress of electrical engineering should be retarded by the telephones and telegraphs claiming to remain monopolists, or whether the necessary modifications should be made to enable them to work side by side with other electrical enterprises. It was highly satisfactory to him to hear Mr. Cottrell speak in such terms of the railway, and state that he had been able to reduce the cost to 3·34d. per train-mile. The arrangement of the switches on the motor cars had not been discussed. It was such that when the brake was applied, the switches immediately flew out and cut off the current from the train.

In comparing the energy used on the City and South London line with that used on the Liverpool Overhead Railway, Mr. Siemens had not given the whole data. The trains at Liverpool were 12 per cent. heavier, ran at an average speed 24 per cent. greater, and made an average of 50 per cent. more stops in the same distance; therefore comparison of energy used was misleading, unless those features were considered. Mr. McDonnell had stated that the trains at Liverpool were suitable for the Overhead Railway because they ran at short intervals and were small trains, but would not be adapted to the District or the Metropolitan Railway. There was no difficulty in running heavy trains at short intervals on the Metropolitan Railway as the light trains were run at short intervals in Liverpool, and with the same proportionate economy, with all the advantages of cleanliness and freedom from combustible gases in the tunnel. In comparing a branch-line locomotive for coal used, it did not appear that Mr. McDonnell had taken into consideration the high speed and number of stops on the Liverpool Overhead Railway. In stating the costs of working, there had been no omission to take into account the depreciation and renewal of stock, as that was part of the contract with the Liverpool Overhead Railway. With respect to the life of the dynamos and electric motors, he had no hesitation in stating that the depreciation would be found to be less than with steam engines, and they were much more easily renewed and repaired. He asserted that the electric system of traction was thoroughly suitable for the Metropolitan Railway, and superior in every respect to the locomotives in use. In discussing mechanical appliances for tramways, to enable motors to be run at constant speed, Mr. Beaumont had dealt with a subject that had engaged much attention; but the difficulty of getting mechanism of any kind to work in the space available, and yet have a reasonable life, had not been surmounted.

The efficiency, 88 per cent., between I.H.P. in the cylinders and

power delivered at the dynamos, had been questioned by Dr. E. Mr. Parker. Hopkinson. This Mr. Parker had referred to in replying to Mr. Preece. The tractive force on the City and South London line with a current of 150 amperes was given by Dr. Hopkinson as 50 lbs. per ton of train. The motors at Liverpool with the same current gave a tractive force of 120 lbs. per ton of train; so it would appear that the motor at Liverpool would start a train twice as heavy with the same current, or be in the same degree more powerful to accelerate the load. A motor must be judged by the manner in which it served the purpose for which it was built. In words Dr. Hopkinson had admitted that the motors were rightly designed, yet had condemned them by figures. The figures would perhaps be correct if the motor ran at a constant speed, but where it was necessary for motors to be constantly starting and accelerating as at Liverpool, the figures given by Dr. Hopkinson did not apply.

Mr. GREATHEAD, in reply, observed that no criticism had been made in reference to the structure, and he would therefore say a few words about other matters. He had hoped more would have been said on behalf of steam-locomotives. Astonishment had been expressed by Mr. McDonnell at the high coal-consumption on the Manhattan Railway, 54 lbs. per train-mile, as compared with the coal-consumption on a small branch line in England; but he had overlooked one very important factor, viz., the distance between the stations. That had a most important effect upon the coal-consumption of a railway. He had the curiosity a few days ago to calculate what the coal-consumption would be upon the Inner Circle of the Metropolitan Railway if the stations, instead of being on an average half a mile apart, were one-third of a mile apart, and found that to obtain the same speed the coal-consumption would be almost doubled. On the Manhattan Railway the stations were about one-third of a mile apart, and the coal-consumption was not excessive for the work the locomotives were doing. Reference had been made to the leakage of 2 or 3 amperes at Liverpool. It was often difficult to determine whether Mr. Preece was serious in making his remarks. Those remarks were made gravely, almost solemnly, but Mr. Greathead concluded from the fact that the Company had never heard anything from the Post Office, that they were not really serious. The leakage of current from the main conductor would readily find its way along the iron structure, and would probably none of it reach the earth. In reference to what Mr. Siemens had said as to the currents required for the motors at Liverpool compared with

Mr. Greathead. those required for the experiments on his locomotives, it might be interesting to give some figures as to the actual current employed in working the two railways. He found at Liverpool, taking the output of the generating-station and the train-miles as the basis of calculation, that during January and February each train on an average took $36\frac{1}{2}$ electrical HP. On the City and South London Railway, where the speed and the weight of train were about the same, the average power taken was 33 electrical HP. per train; so that in the actual work there was very little difference. But in the case of the Liverpool line, there were included in the demands upon the current the working of the brakes, the working of the automatic signals and of the tools at the shop, and also the lighting of the generating-station, the stations and the trains. Further, the trains had to make a great many more stops, the average distance between the stations on the City and South London Railway being about 1,100 yards, while on the Liverpool Overhead Railway it was only 750 yards. On the former line, the lighting of the trains and stations was included, and formed, of course, a larger portion of the whole than at Liverpool, the lights being required throughout the day's working.

Correspondence.

Mr. Aspinall. Mr. JOHN A. F. ASPINALL thought it had been attempted to compare to a certain extent the working of an electric line with an ordinary railway worked by locomotives, somewhat to the disadvantage of the latter, and that it would be well in the early stage of such comparisons to put the figures upon a proper footing. The working expenses for motive power had been stated in the Paper to be about 4*d.* per train-mile, and the consumption of fuel at about 16 lbs. per train-mile for trains of about 38 tons weight, running at 12 miles per hour; and those figures were compared with statistics of the New York Elevated Railway where 54 lbs. of coal were used per train-mile. If the comparison was to be a fair one, electrical railways, such as had hitherto been constructed in England, should not use the train-mile as the divisor for the figures of the main lines of the country. When dealing with railways worked by locomotives, the engine-mile was the only figure which could be applied in order to put the comparison upon a proper basis. In order to explain this, if an ordinary railway had 1,000 engines, it was quite possible that 300 of them might